

**DRILLING AUTOMATION TESTS AT A LUNAR/MARS ANALOG SITE.** B. Glass<sup>1</sup>, H. Cannon<sup>1</sup>, S. Hanagud<sup>2</sup>, P. Lee<sup>3</sup>, G. Paulsen<sup>4</sup>, <sup>1</sup>NASA Ames Research Center, Moffett Field, CA 94305, USA, Email: [brian.glass@nasa.gov](mailto:brian.glass@nasa.gov), <sup>2</sup>Georgia Institute of Technology, Atlanta, GA 30332, USA, <sup>3</sup>SETI Institute, Mountain View, CA 94305, USA, <sup>4</sup>Honeybee Robotics, 460 West 34th Street, New York, NY 10001, USA.

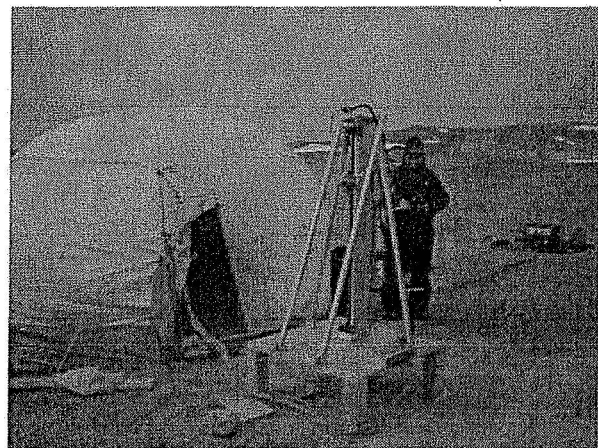
**Summary:** Future in-situ lunar/martian resource utilization and characterization, as well as the scientific search for life on Mars, will require access to the subsurface and hence drilling. Drilling on Earth is hard – an art form more than an engineering discipline. The limited mass, energy and manpower in planetary drilling situations makes application of terrestrial drilling techniques problematic. The Drilling Automation for Mars Exploration (DAME) project is developing drilling automation and robotics for projected use in missions to the Moon and Mars in the 2011-15 period. This has been tested recently, drilling in permafrost at a lunar/martian analog site (Haughton Crater, Devon Island, Canada).

**Introduction:** Space drilling will require intelligent and autonomous systems for robotic exploration and to support future human exploration, as energy, mass and human presence will be scarce. Unlike rover navigation problems, most planetary drilling will be blind – absent any precursor seismic imaging of substrates, which is common on Earth prior to drilling for hydrocarbons. The search for evidence of extant microbial life on Mars drives the need for the eventual acquisition of core samples from subsurface depths estimated at hundreds to thousands of meters where, beneath permafrost, the increasing temperature would be consistent with the presence of interstitial water (as a brine) in its liquid phase. On the Moon, eventual in-situ resource utilization (ISRU) will require deep drilling with probable human-supervised operation [1] of large-bore drills, but initial lunar subsurface exploration and near-term ISRU will be accomplished with lightweight, rover-deployable or standalone drills capable of penetrating a few tens of meters in depth.

The Drilling Automation for Mars Exploration (DAME) project's purpose is to develop and field-test drilling automation and robotics technologies for projected use in missions in the 2011-15 period [2]. Figure 1 shows a lightweight, 20kg Mars-prototype drill, in DAME summer Arctic field testing [3]. This includes control of the drilling hardware, state estimation of both the hardware, and the lithography being drilled and the state of the hole.

**Approach:** Drilling on Earth is hard – an art form more than an engineering discipline. Human operators listen and feel drill string vibrations coming from kilometers underground. A drill system for planetary deployment will differ in many ways from

conventional drilling systems where mass, power and volume are not major considerations and where the speed of penetration is essential for economic operation. On the Moon or Mars, working in a very low temperature/pressure desiccated environment without drilling fluids, the basic task of reliably comminuting the rock and moving the cuttings away from the drill bit and up to the surface will itself be a challenge [4]. The environment will be minimally characterized and we can expect to encounter a range of different rock types ranging from regolith to ice to solid basalts, without knowing which rock type we will encounter next. Mass considerations prevent the transport and use of drilling mud.



**Fig. 1. 20kg Honeybee Mars-prototype drill [3], tested with vibration sensors in the summer on 2004 on Devon Island, Nunavut, Canada.**

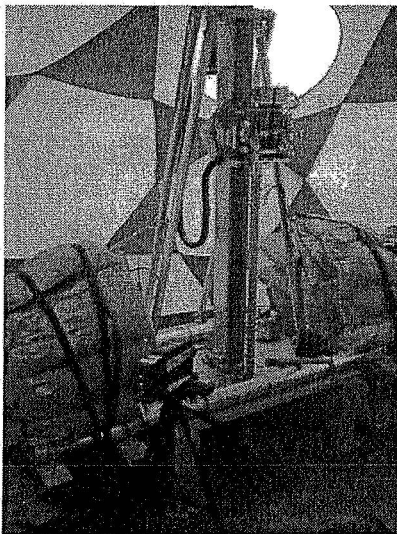
Lightweight dry drills may break or become stuck quickly in some failure modes, or may degrade progressively in others (such as ice-necking or bit wearout). And the layers being drilled are not known a priori, without prior seismic or other regional surveys... so some apparent wearout or rapid drill faults may actually reflect penetration into subsequent strata (with different mechanical properties). Our approach is to apply three types of automation:

- (a) real-time limit-checking and safing, using a rule-based approach to monitor motor torques and temperatures;
- (b) near-real-time vibration measurement and fast frequency-domain pattern-matching using a neural net; and

- (c) in-line prognosis of degradation and wearout using model-based reasoning.

Part (a) is being implemented in the drill executive and control software, while (b) and (c) will be separate diagnostic/prognostic software modules.

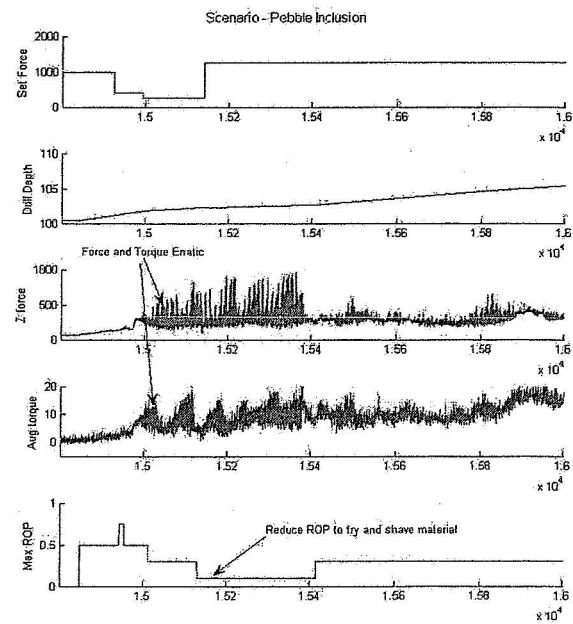
**Results:** The drill was deployed at two sites at Haughton Crater, operating at Mars-relevant power levels (max 150-200W). Over eight days, it drilled 2.2m in permafrost and the regolith-like breccia found in the Haughton impact crater. Eight drill faults were demonstrated during testing, as well as nearly 50 hours of nominal operations. Drilling operations were halted periodically in order to capture the vibrational signature of the drill at different depths/lengths.



**Figure 2.** 2005 DAME drilling tests in the Canadian Arctic demonstrated autonomous fault diagnosis while penetrating mixed rock and ice layers at the Haughton Crater analog site.

In the DAME field tests in July 2005 in Haughton Crater in the Canadian Arctic, in addition to testing mechanical drill operations, the DAME team integrated the Honeybee Robotics drill with the NASA-developed automated controls. DAME is intended to develop and test drill fault diagnosis and recovery, so the observe-only diagnostics and monitoring fielded in summer 2005 tests at Haughton will lead to the DAME software in hands-off control of drilling in the summer of 2006. The 2005 DAME tests, shown in Figure 2, used two diagnostic agents – one that used model-based reasoning from sensor values [2], the other a neural network that perceived the vibrational frequency and modal signatures of the drill shaft [5] – which were successfully tested, independently detecting five fault states and reporting their findings to the executive, which itself was developed for the MARTE project [6, 7]. Figure 3

shows the drill response to an ice-embedded pebble beginning at 102 cm depth, and corrective actions taken.



**Fig. 3.** 2005 field test example – ice-cemented pebble, jamming the auger at 102cm depth.

**Conclusions:** The Drilling Automation for Mars Exploration (DAME) project is developing and testing standalone automation at a lunar/martian impact crater analog site in Arctic Canada. The search for resources and past/present life on other planetary bodies will require subsurface access, which requires exploratory drilling. Drilling has been a hard, human-intensive problem in terrestrial applications, but planetary drills require automation. The DAME project has taken initial steps toward developing hardware and software, two complementary diagnostic approaches, and completing two field tests leading to drilling automation. Full hands-off automation is expected to be tested in the next 2006 Arctic field season.

**Acknowledgements:** The DAME project is part of the NASA Mars Instrument Development Program.

**References:** [1] Glass, B. and G. Briggs (2003) *iSAIRAS 2003*, Nara, Japan. [2] Glass, B. et al. (2005) *iSAIRAS 2005*, Munich, Germany. [3] Paulsen, G.L. et al. (2006) *submitted to 37<sup>th</sup> LPSC*. [3] Blacic, J. et al. (2000) *AIAA Space 2000*, Long Beach, CA, Paper AIAA-2000-5301. [4] Luo, H. and S. Hanagud (1996) *Technical Report*, Georgia Institute of Technology, School of Aerospace Engineering. [5] Stoker, C. et al. (2004) *35<sup>th</sup> LPSC*, Abstract 2025. [6] Stoker, C. et al. (2005) *36<sup>th</sup> LPSC*, Abstract 1537.